4.0 Filtration and Drainage

- Geotextile filtration
- Geocomposite edge drains
- Geocomposite sheet drains
- Geocomposite wick drains

4.1 Geotextile Filtration

- **Refers to cross-plane flow, i.e., GT is acting as a filter <u>not</u> as a drain**
- **Many applications**
  - **behind retaining walls**
  - **under erosion control systems**
  - **around pavement underdrains**
- **Three design mechanisms involved:**
  1. **adequate flow**
  2. **proper soil retention**
  3. **long-term flow equilibrium**

1. Adequate Flow

- Many suggested rules, in general;

$$k_{GT} > (0.1 \text{ to } 10)\, k_{soil}$$

- Alternate is to work with permittivity

$$\psi = k_n/t$$

and formulate a flow FS:

$$FS = \psi_{allow}/\psi_{reqd}$$

- Both assume validity of Darcy's Law (q = k i A probably OK for GT's)
- ψ_{allow} from ASTM D4491 for candidate geotextile (must include RF's)
- ψ_{reqd} from site specific flow conditions; via flow net, tables, guides, etc.

2. Proper Soil Retention

- Many , many suggested rules, of following form:

  $0_{15,\ 50,\ 95,\ \text{etc.}} \leq (1 \text{ to } 37)\ d_{15,\ 50,\ 85,\ 95,\ \text{etc.}}$

- Carroll's formula is often used:

  $0_{95} < (2.5)\ d_{85}$

- Value of 0_{95} for candidate geotextile from ASTM D4751
- Value of d_{85} (or other property) from the site specific upstream soil gradation

3. Long-Term Flow Equilibrium

- Some guidelines based on k_{GT} vs. k_{soil}, or on minimum permittivity
- Problematic soils are generally known:
  - fine cohesionless silts (like loess and rock flour)
  - gap graded cohesionless soils
  - turbid groundwater, e.g., from dredging operations
  - high alkalinity soils
  - microorganism laden fluids, e.g., farm runoff and landfill leachate
- Option is always to conduct lab tests (more later):
  - long term flow test
  - gradient ratio test
  - hydraulic conductivity ratio test

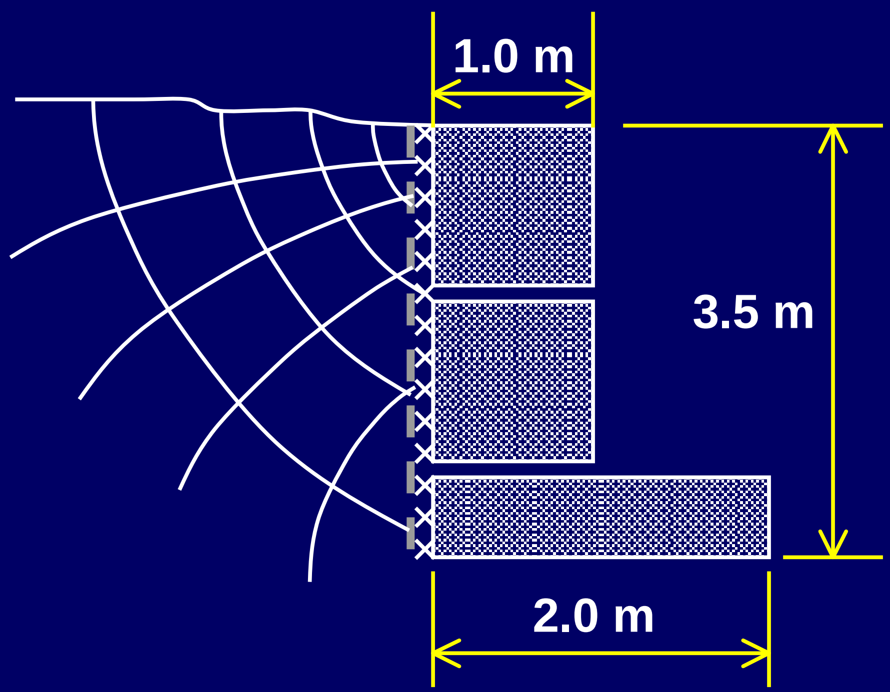
Retaining Wall Filters

Example: retaining wall filter

Given a 3.5 m high gabion wall as shown below. The backfill soil is a medium-density silty sand of k = 0.0075 m/s and d_{85} = 0.15 mm. The properties of the candidate geotextile are ψ = 2.0 sec^{-1} and 0_{95} = 0.30 mm (#50 sieve). Is this geotextile adequate for flow and soil retention?

Solution: (a) Determine flow rate factor-of-safety

- **Calculate the actual flow rate using a net as shown**



$$q = kh\left(\frac{F}{N}\right)$$

$$= (0.0075)(3.5)\left(\frac{4}{5}\right)$$

$$= 0.021\ m^3/s\text{-}m, \quad \text{or} \quad m^2/s$$

Example: retaining wall filter *(cont'd)*

- Calculate the required permittivity

$$q = kiA$$

$$q = k\,\frac{\Delta h}{t}\,A$$

$$\frac{k}{t} = \frac{q}{(\Delta h)(A)}$$

$$\psi_{reqd} = \frac{0.021}{(35)(3.5 \times 1)}$$

$$= 0.00171 \ \text{sec}^{-1}$$

- Calculate the allowable permittivity using site specific reduction factors, e.g., ΠRF = 15.0

$$\psi_{allow} = \psi_{ult}/15$$

$$= 2.0/15$$

$$= 0.13 \ \text{sec}^{-1}$$

- Calculate the factor-of-safety

$$FS = \psi_{allow}/\psi_{reqd}$$

$$= 0.13/0.00171$$

$$= 76, \text{ OK}$$

Example: retaining wall filter *(cont'd)*

Solution:

(b) Determine the adequacy of soil retention

- **Using Carroll's formula**

$$0_{95\,(reqd)} \le 2.5\, d_{85}$$
$$\le 2.5\,(0.15)$$
$$\le 0.375 \text{ mm}$$

- **Check against candidate geotextile's actual 0_{95}**

$$0_{95\,(act.)} < 0_{95\,(reqd)}$$
$$0.3 < 0.375, \text{ OK, alternatively}$$
$$FS = 0.375/0.30 = 1.25, \text{ OK.}$$

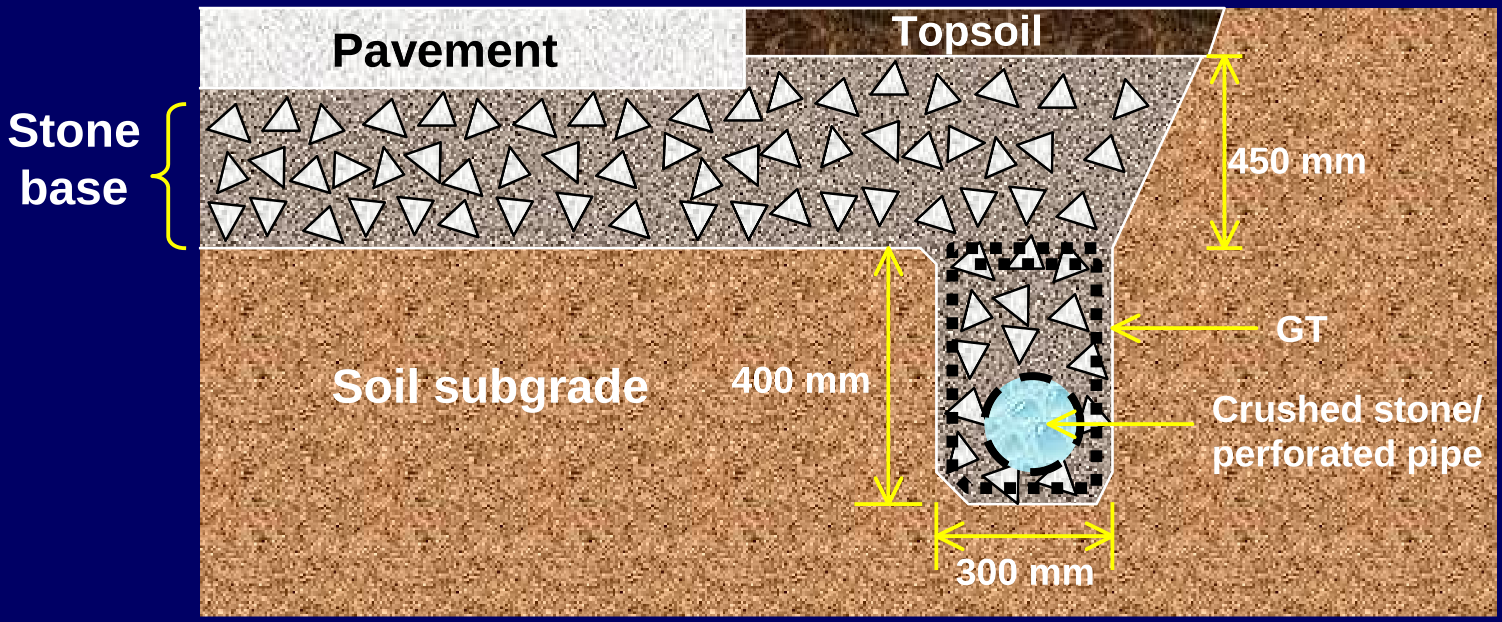
(c) Assess if proper balance between flow and soil retention exists for site specific conditions, i.e., perhaps a tighter GT.

(d) If problematic soil, check against long term excessive clogging.

GT Filter for Highway Underdrain

Example: highway underdrain filter

Design the geotextile filter surrounding an open-graded stone aggregate which in turn surrounds a perforated pipe underdrain, as shown in the sketch below. Flow will enter through the stone base from the upper part of the underdrain, while soil retention must be assured against the surrounding native soil. This soil is a sandy silt (ML) with d_{85} = 0.028 mm. The geotextile being considered is a needle-punched nonwoven with ψ_{ult} = 1.5 sec^{-1} (use ΠRF = 25) and AOS of 0.212 mm (#70 sieve).



Example: highway underdrain filter *(cont'd)*

(a) Regarding the flow factor of safety; estimate the maximum flow coming to the geotextile. This will be through the 450 mm stone base beneath the pavement. Cedegren has numerous design charts, from which we have selected a relatively high value of 15 m^3/day-m.

Calculate the required permittivity:

$$q = kiA$$

$$= k\frac{\Delta h}{t}A$$

$$\frac{k}{t} = \frac{q}{\Delta hA}$$

$$= \frac{15}{(0.45)(0.30\times 1)}$$

$$\psi_{reqd} = 111 \ \text{day}^{-1} = 0.0013 \ \text{sec}^{-1}$$

Check the above required permittivity against the allowable permittivity of the geotextile:

$$\psi_{allow} = \psi_{ult} / \Pi RF$$

$$= 1.5 / 25$$

$$= 0.06 \ \text{sec}^{-1}$$

$$FS = \psi_{allow} / \psi_{reqd}$$

$$= 0.06 / 0.0013$$

$$= 46 \quad \text{OK}$$

Example: **highway underdrain filter *(cont'd)***

(b) Check against excessive soil loss using Carroll's relationship

$$0_{95} < 2.5\, d_{85}$$
$$< 2.5\ (0.028)$$
$$0_{95\ (reqd)} < 0.070\ \text{mm}$$

The candidate geotextile has an AOS = #100 sieve (= 0.149 mm), therefore

$$0_{95\ act} \overset{?}{\leq} 0_{95\ reqd}$$

$$0.149 > 0.070,\quad \text{NG, alternatively}$$

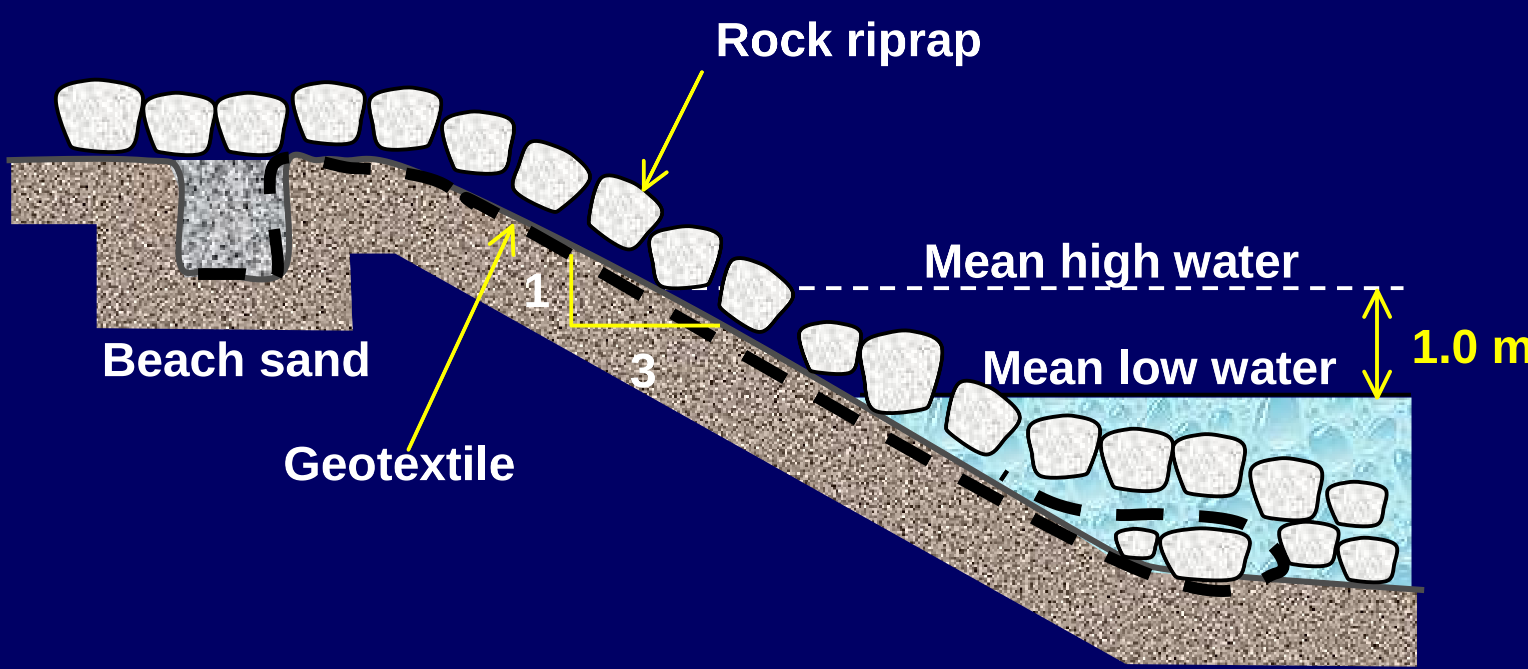
$$\text{FS} = 0.70 / 0.149 = 0.47, \text{ also NG.}$$

This geotextile is too open and excessive soil loss will occur. Another, and tighter, geotextile will have to be chosen which can be readily found since the flow rate FS is very high.

GT Filter for Erosion Control

Example: erosion control filter

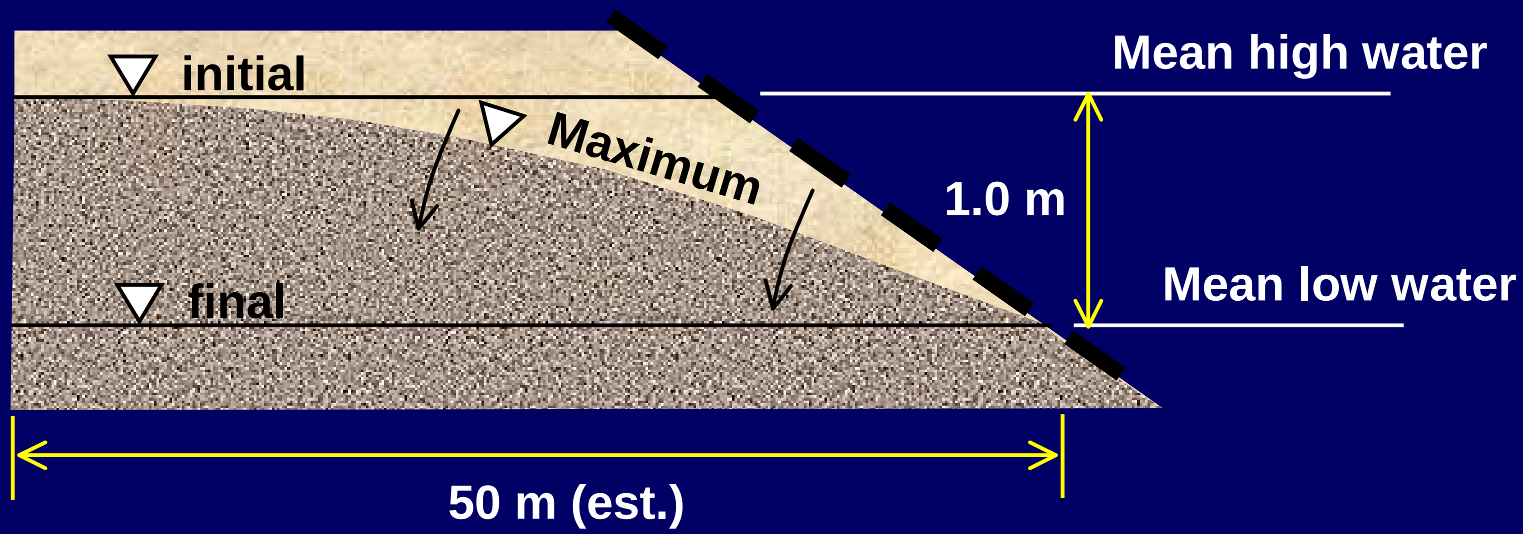
Evaluate the filtration adequacy of a candidate geotextile for placement beneath a rock riprap erosion control system in a coastal area with 1.0 m tides (i.e., reversing flow conditions) as shown in the following sketch. The geotextile laboratory properties are ψ_{ult} = 0.50 sec^{-1}, and AOS = 0.21 mm, i.e., a No. 70 sieve. The in-situ soil is a beach sand (SP) with d_{15} = 0.17 mm, CU = 3.5; in a medium-dense condition D_R = 75% at a porosity of 0.40.



Example: erosion control filter *(cont'd)*

Solution: As with all filtration designs this is a two-part problem, one for adequate flow and the other for soil retention.
For (a) adequate flow, the procedure is as follows.

• Estimate the maximum flow rate due to the 1.0 m tidal lag. If we assume a water profile as follows:



Example: erosion control filter *(cont'd)*

With the tide receding at a max. rate during an initial 2-hr. period as shown;

$$q_{max} = \frac{50 \times 1 \times 1}{2} \times \frac{0.4}{2}$$

$$= 5.0 \ m^3 / hr - m$$

$$= 0.00139 \ m^2 / s$$

Using this value the required permittivity is:

$$q = kiA$$

$$= k \frac{\Delta h}{t} A$$

$$\frac{k}{t} = \frac{q}{\Delta ha}$$

$$= \frac{0.00139}{(1.0)(3.16)}$$

$$\psi_{reqd} = 0.00044 \, s^{-1}$$

Example: erosion control filter *(cont'd)*

• The allowable permittivity is found using reduction factors for soil blinding, creep, intrusion, chemical and biological clogging. Since rock covers much of the GTs surface, the blinding value is used as its maximum value of 10.0 since the rock will cover a large portion of the geotextile's surface area.

$$\psi_{allow} = \psi_{ult}\left[\frac{1}{FS_{SCB} \times FS_{CR} \times FS_{IN} \times FS_{CC} \times FS_{BC}}\right]$$

$$= 0.50\left[\frac{1}{10.0 \times 1.2 \times 1.2 \times 2.5 \times 3.0}\right] = 0.50\left[\frac{1}{108}\right]$$

$$= 0.0046 \ \ s^{-1}$$

The global factor of safety is then

$$FS = \frac{\psi_{allow}}{\psi_{reqd}} = \frac{0.0046}{0.00044} = 10, \quad \text{acceptable}$$

Example: erosion control filter *(cont'd)*

(b) The geotextile is now evaluated with respect to its adequacy to retain the soil beneath it.

Since these erosion control structures are destroyed when the contained soil passes through the geotextile voids (resulting in subsidence and loss of stability of the riprap), and the flow regime is pulsating and cyclic we will use the Christopher and Holtz criterion

$$0_{95} \leq d_{15}$$
$$0_{95\ (reqd)} \leq 0.17\ \text{mm}$$

The candidate geotextile has an AOS value of 0.21 mm, hence

$$0_{95\ (act)} \overset{?}{\leq} 0_{95\ (reqd)}$$

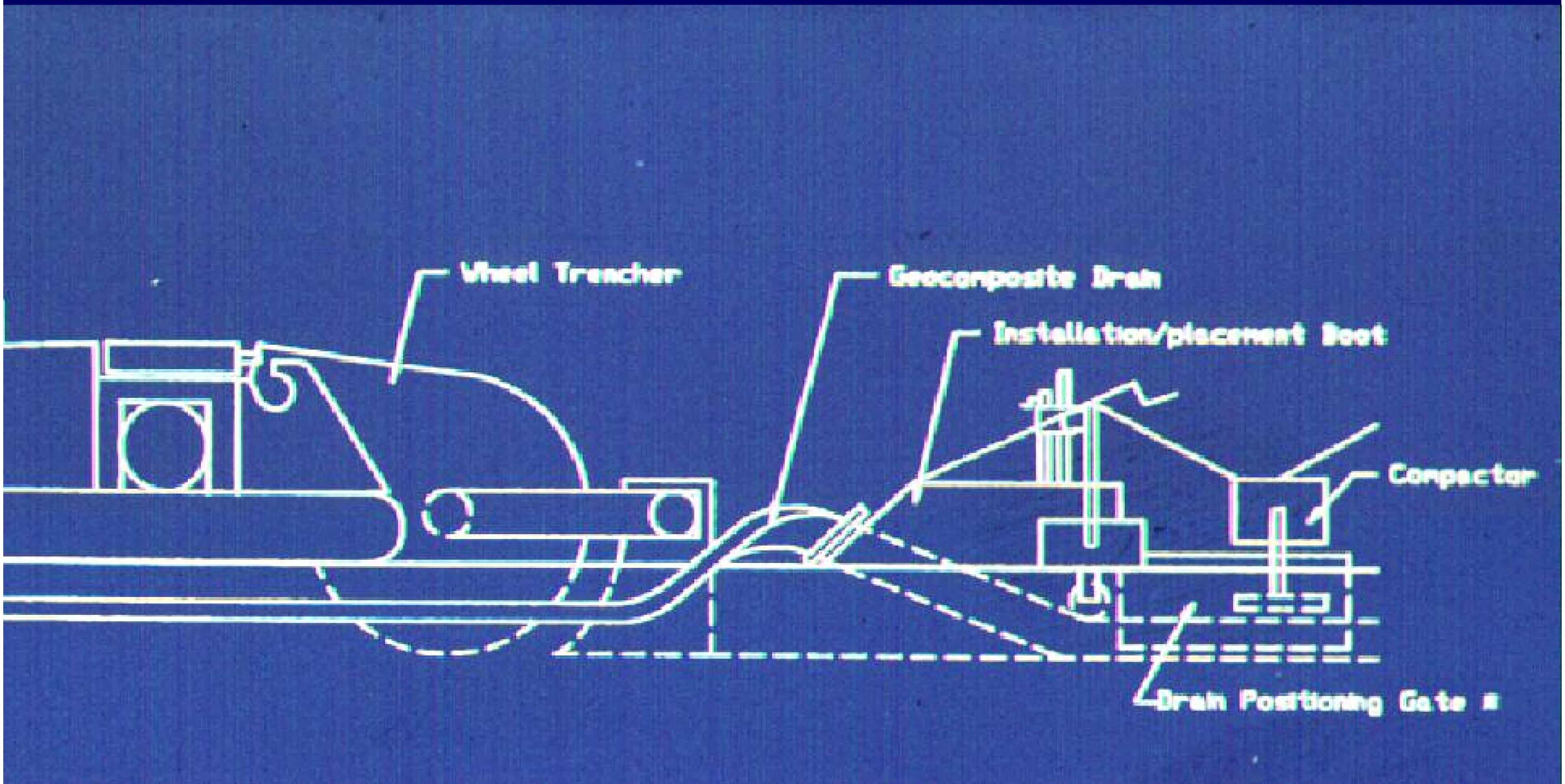
$0.21 > 0.17$, therefore **NG**

The candidate geotextile is too open, soil loss will occur and a different geotextile (one that is slightly more closed, hence tighter voids) must be considered.

Other Filtration Applications

4.2 Geocomposite Edge Drains

- prefabricated (panel) drains consisting of a drainage core with GT filter/separator wrapped around entire core
- numerous manufactured types
- used for base course/subgrade drainage in both retrofitted and new pavements



Wheel Trencher
Geocomposite Drain
Installation/placement Boot
Compactor
Drain Positioning Gate

Design aspects to be considered

ref. Koerner and Hwu, TRB No. 1329, 1991

Regarding the geotextile

- adequate flow rate
- adequate soil retention
- long term flow equilibrium, and
- sufficient strength

Regarding the core

- adequate crush strength
- adequate flow rate (example follows)

Example: highway edge drain

The maximum anticipated flow rate to a highway edge drain is 1150 l/hr. What is the factor of safety using a geocomposite edge drain whose index test value is 4000 l/hr.

Solution: First calculate an allowable flow rate along with the reduction factors tuned to the site-specific conditions.

$$q_{allow} = q_{ult}\left[\frac{1}{RF_{IN} \times RF_{CR} \times RF_{CC} \times RF_{BC}}\right]$$

$$= 4000\left[\frac{1}{1.3 \times 1.5 \times 1.2 \times 1.1}\right] = 4000\left[\frac{1}{2.57}\right]$$

$$= 1560 \quad l/hr.$$

The calculate the flow-rate factor of safety in the conventional manner:

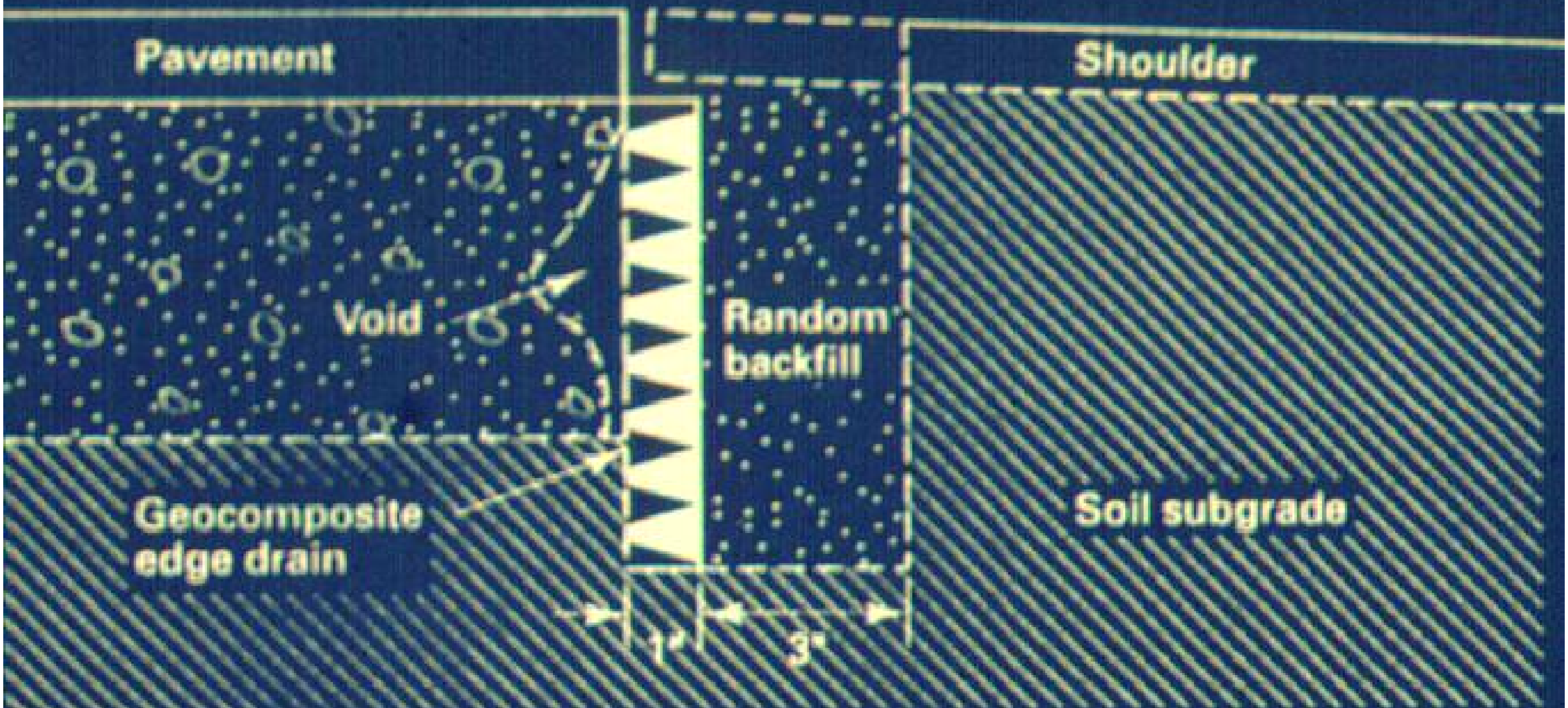
$$FS = \frac{q_{allow}}{q_{reqd}}$$

$$= \frac{1560}{1150} = 1.4 \quad \text{OK}$$

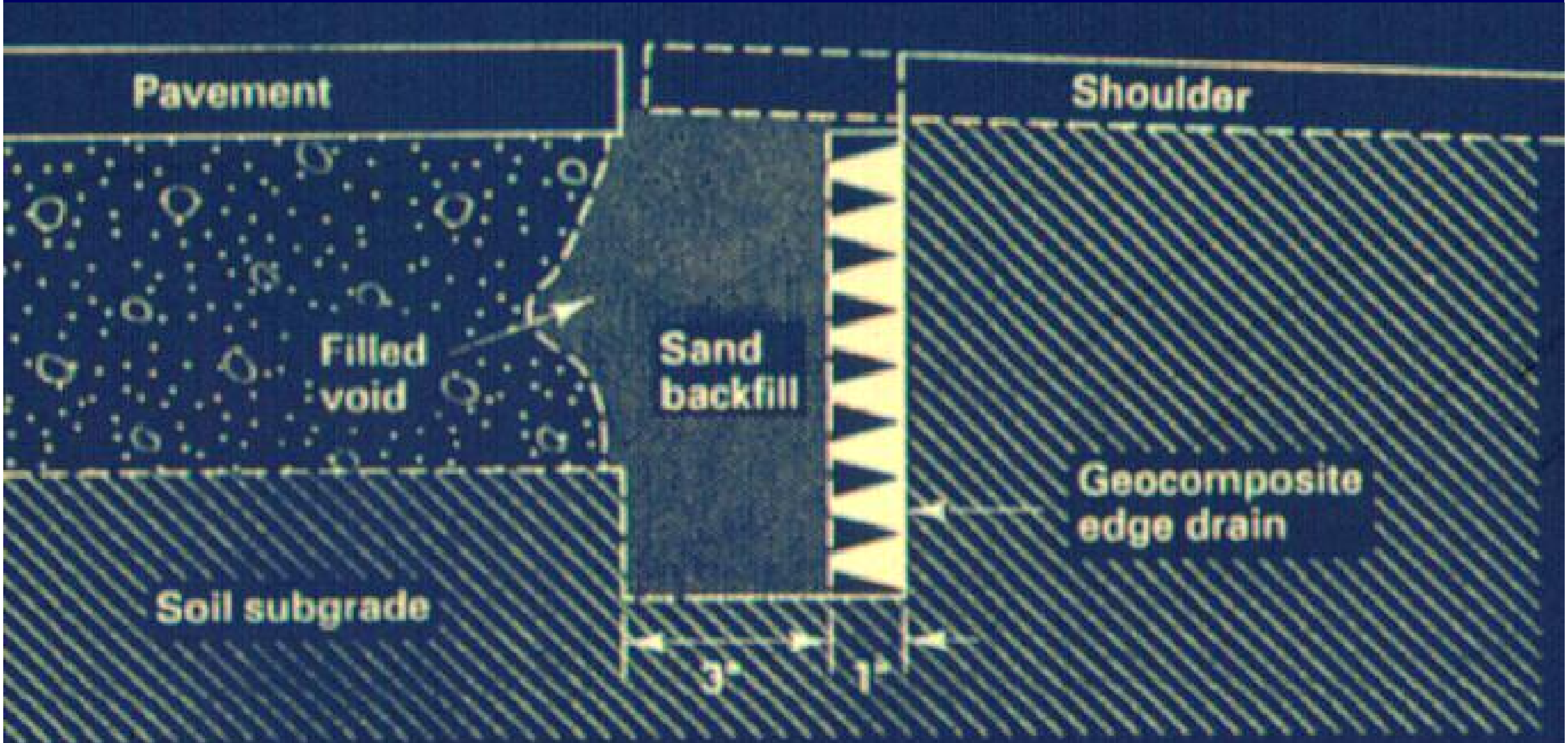
Comments on GC Edge Drains

- very economical systems (~ $3.00/lin. meter less than other drainage systems)
- most DOTs are heavily involved in trial sections and exhuming, or they use these products extensively
- GRI study found major problem to be lack of GT soil retention (hence core clogging) due to poor intimate contact of GT to upstream soil
- Recommended sand backfill <u>upstream</u> of edge drain in NCHRP Rept. 367, 1994, see following discussion

Field Problems Have Been Observed due to Inadequate Soil Retention by GT Filter



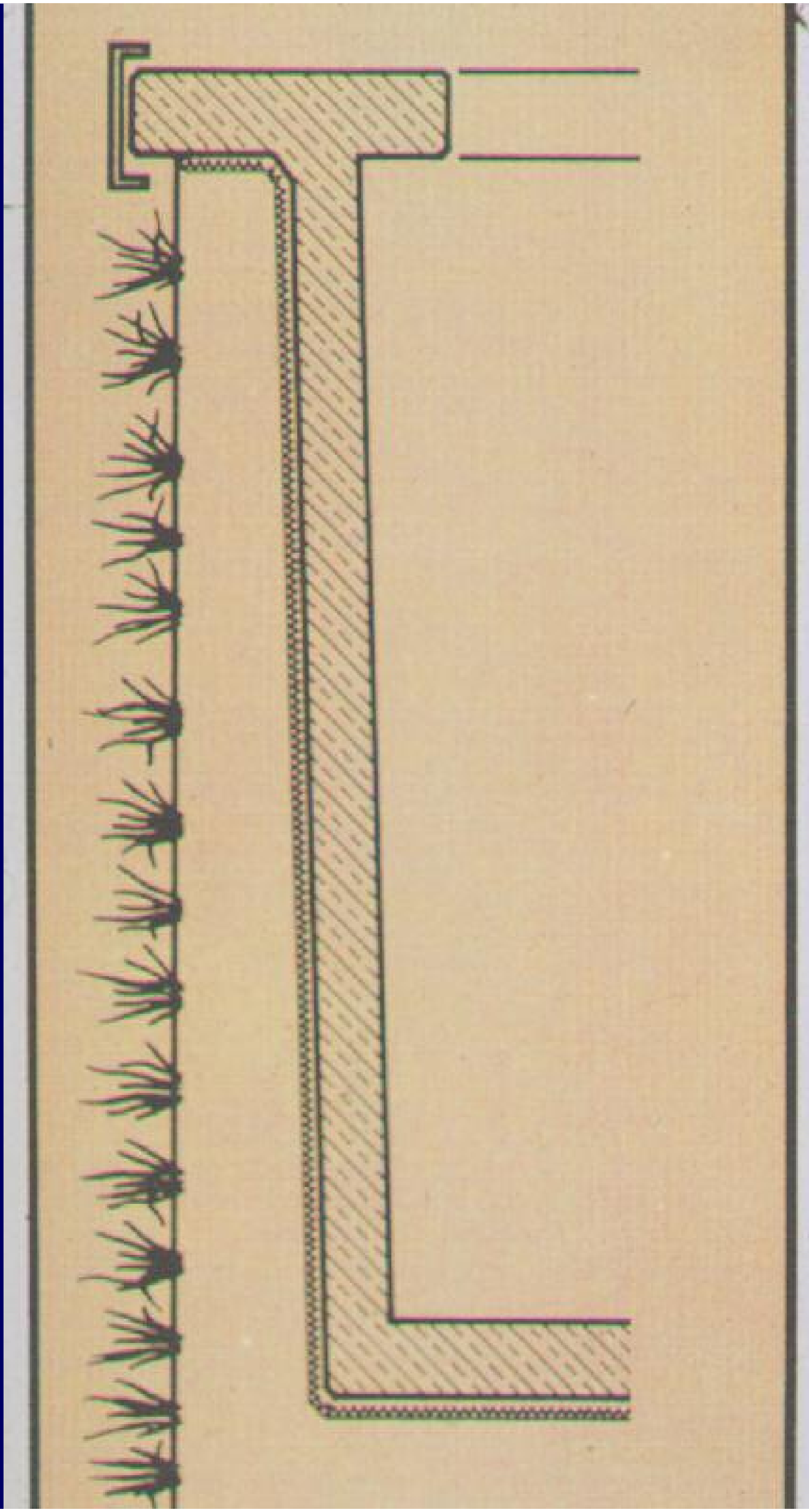
(a) Occurence of large void beneath pavement slab preventing intimate contact of geotextile to upstream stone base and subgrade soil.

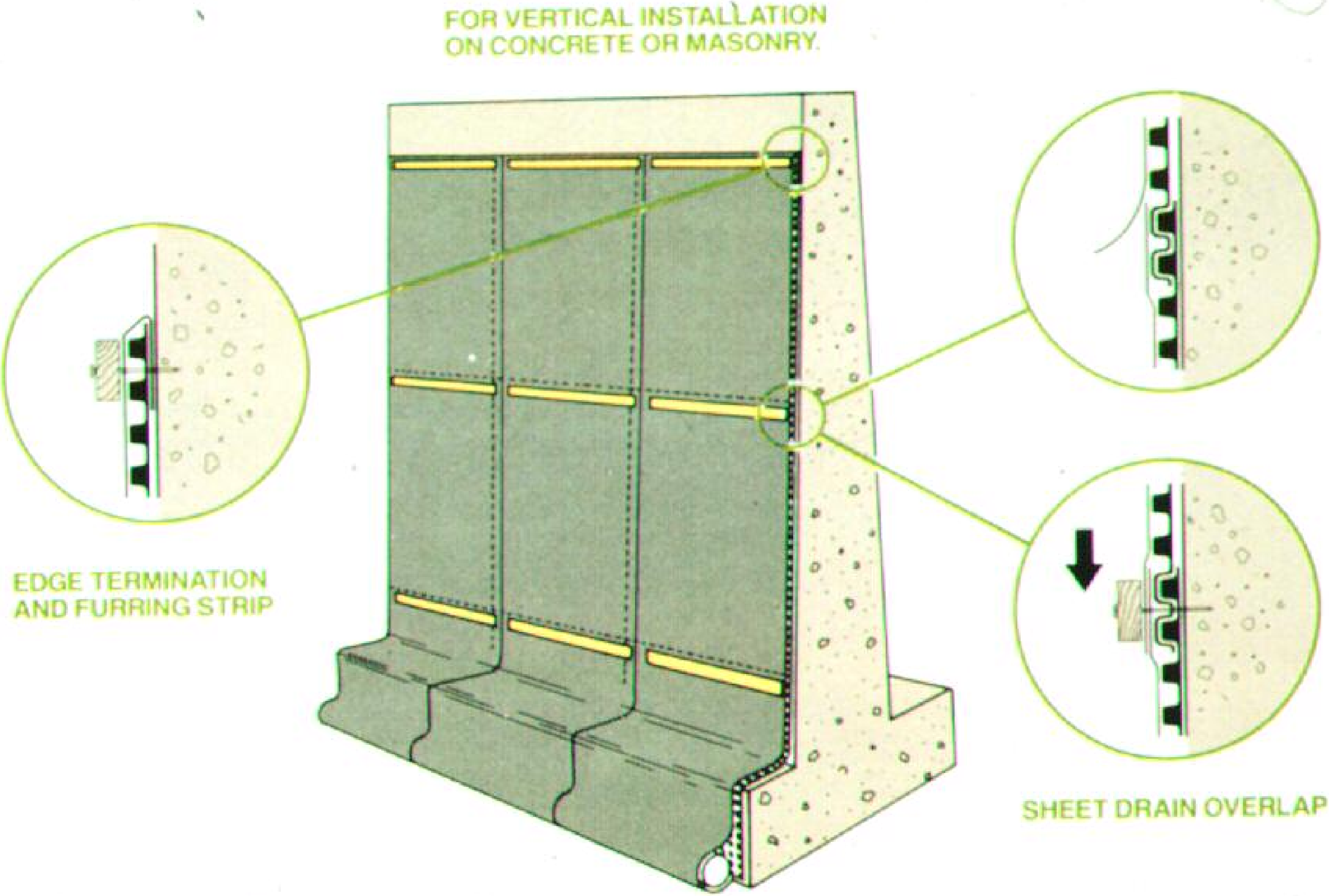


(b) Suggested remedy to large voids via slurried sand backfill with geocomposite edge drain moved to shoulder side of trench.

4.3 Geocomposite Sheet Drains

- consists of drainage core with GT filter /separator on backfill side
- numerous manufacturers
- each has different types and styles
- major uses are retaining wall drainage and plaza deck drainage





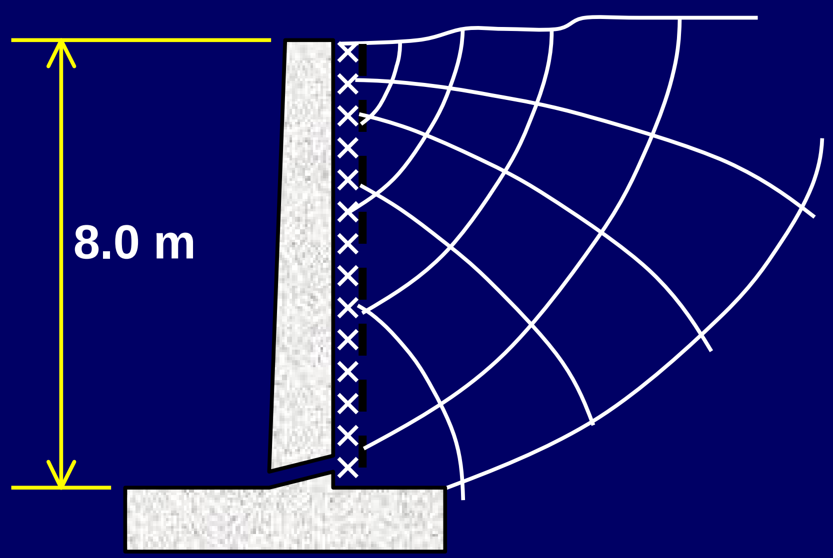
FOR VERTICAL INSTALLATION
ON CONCRETE OR MASONRY.
EDGE TERMINATION
AND FURRING STRIP
SHEET DRAIN OVERLAP

Example: retaining wall drainage

Calculate the flow rate FS for a geocomposite sheet drain behind the following cantilever retaining wall. The soil backfill is ML-SW with a k = 5 × 10^{-5} m/s. The ultimate flow rate of the product under consideration is 0.216 m^3/min-m width at a hydraulic gradient of 1.0 and at the maximum design stress. Use combined reduction factors of 3.0.

Solution: **Using the following flow net**

(a) calculate the maximum flow rate coming to the geocomposite drain.



$$q = kh\left(\frac{F}{N}\right)$$

$$= (0.00005)(60)(8)\left(\frac{5}{5}\right)$$

$$= 0.024 \ m^2/\text{min.}$$

Example: retaining wall drainage *(cont'd)*

(b) Convert the lab value of flow rate to a site specific allowable flow rate

$$q_{allow} = q_{ult}/\Pi RF$$

$$= 0.216/3.0$$

$$= 0.072\ m^2/min$$

(c) Calculate the flow rate factor-of-safety

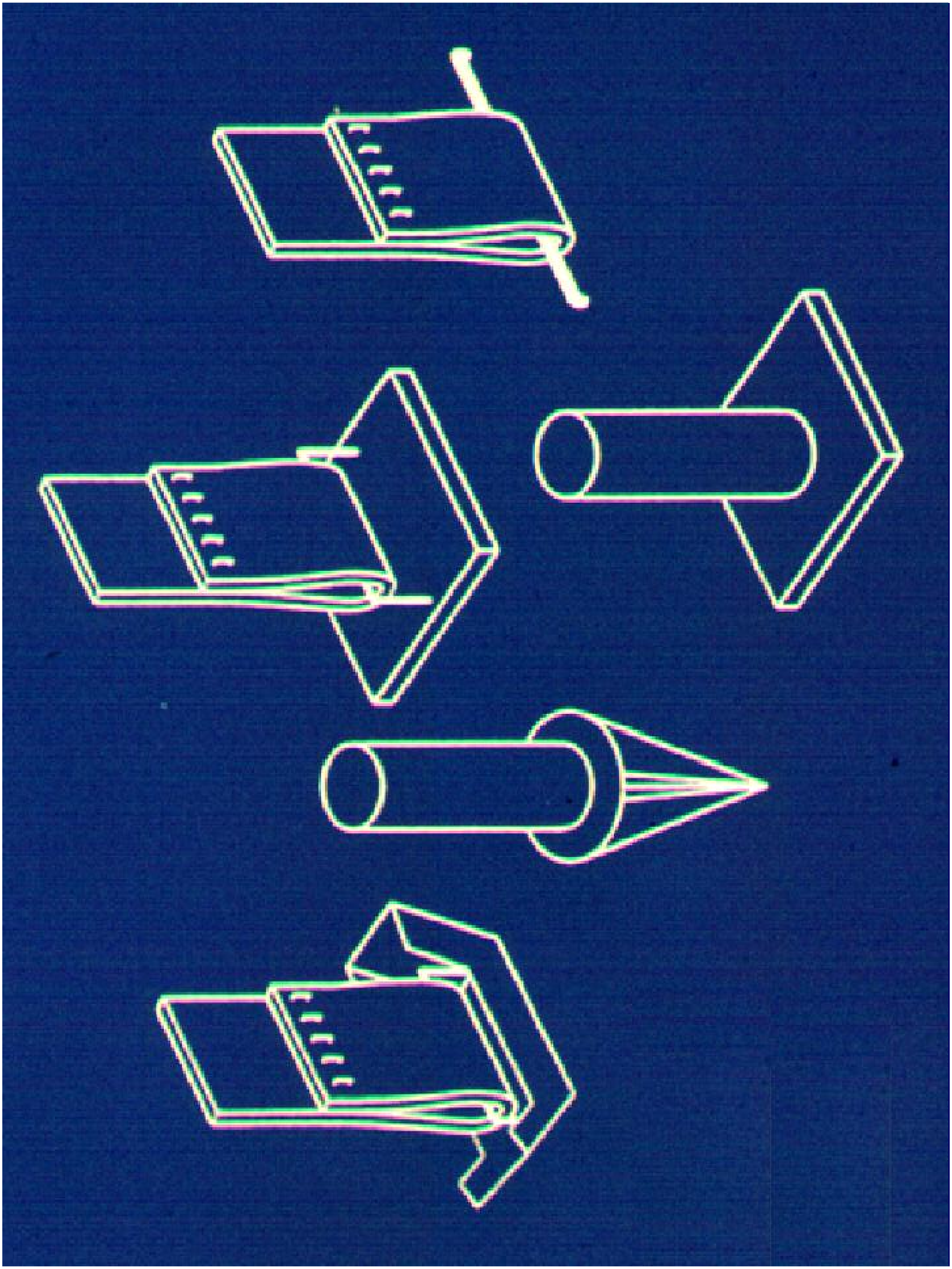
$$FS = q_{allow}/q_{reqd}$$

$$= 0.072/0.024$$

$$FS = 3.0,\ OK$$

4.4 Geocomposite Wick Drains

- also called prefabricated vertical drains (PVDs)
- used for rapid consolidation of saturated fine grained soils
- have essentially replaced sand drains
- consists of a drainage core with a GT filter/separator wrapped completely around it
- typically 100 mm wide, by 2 to 10 mm thick, by ±100 m long (in roll or coil form)
- design adapted by Hansbo for calculation of consolidation time which is the variable to focus upon



Example: wick drain

Calculate the times required for 50%, 70% and 90% consolidation of a saturated clayey silt soil using wick drains at various triangular spacings. The wick drains measure 100 by 4 mm and the soil has a $c_h = 6.5 \times 10^{-6}$ m^2/min.

Solution:

Using the formula of Hansbo:

$$d = \frac{100 + 100 + 4 + 4}{\pi}$$

$$= 66.2 \text{ mm}$$

so

$$t = \frac{D^2}{8\left(6.5 \times 10^{-6}\right)} \left(\ln \frac{D}{0.0662} - 0.75 \right) \ln \frac{1}{1 - \bar{U}}$$

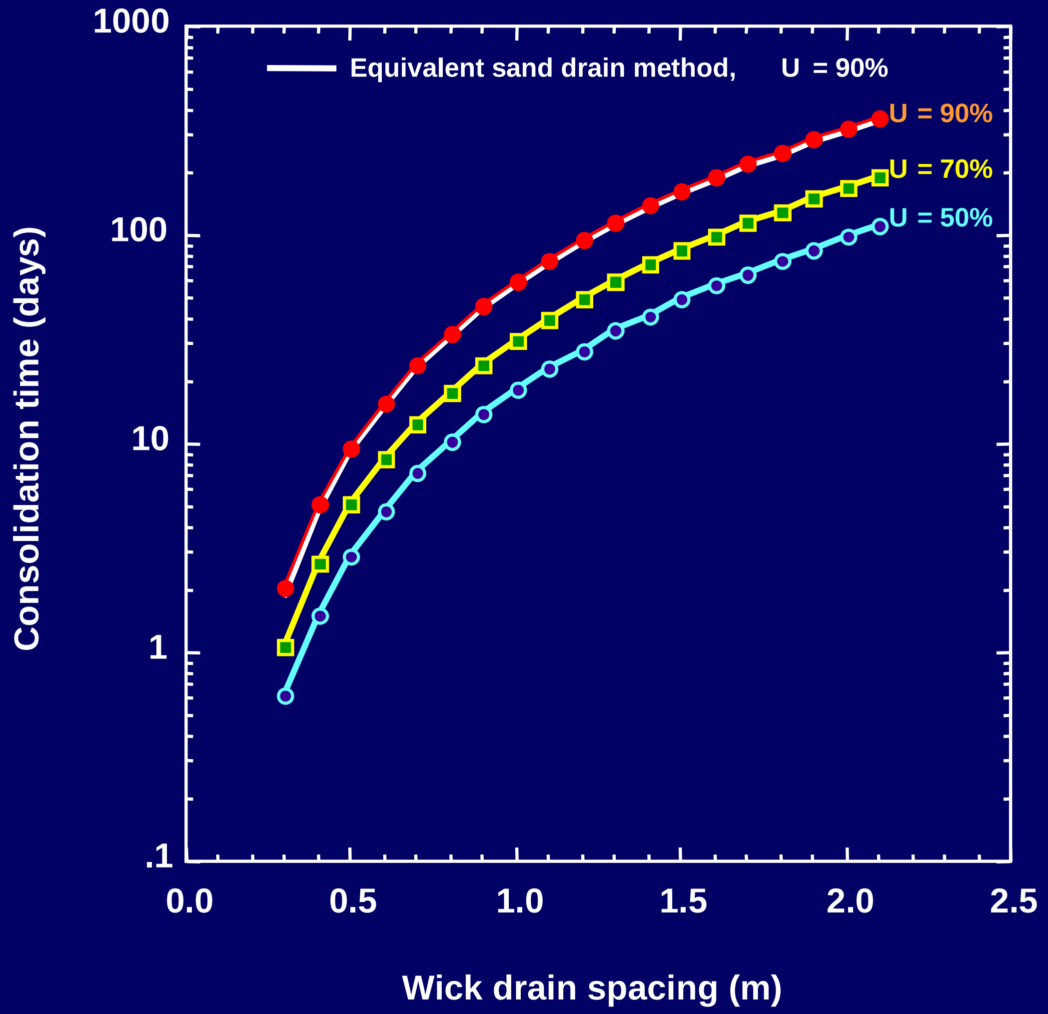
which results in the following table for consolidation time in minutes (the equivalent number of days are in parentheses):

Results of the wick drain example problem

Theoretical Wick Drain Spacing,	Targeted Percent Consolidation ($\overline{U}$)					
D (m)	50%		70%		90	
2.1	159,000	(110)	276,000	(192)	529,000	(367)
1.8	110,000	(77)	192,000	(133)	366,000	(254)
1.5	71,000	(49)	123,000	(86)	236,000	(164)
1.2	41,000	(29)	72,000	(50)	137,000	(95)
0.9	20,000	(14)	35,000	(24)	67,000	(46)
0.6	7,000	(4.8)	12,000	(8.4)	23,000	(16)
0.3	910	(0.6)	1,590	(1.1)	3,030	(2.1)

These values are now plotted for the required design curves. Note that the D spacings must be decreased by 1.05 using a triangular wick drain pattern. Also, when compared to the results using the equivalent sand drain method, these values seem to agree very closely, e.g, note the 90% consolidation curves agreement.

Results of the wick drain example problem



Comments on GS Wick Drains

- commonly used with high strength GTs placed on soft foundation soils
- kinking of drain core under large settlements should be assessed by lab testing
- foundation stability strength is increased due to tensile strength of wick drains
- surprisingly, neither GT nor core clogging seem to be a problem

End of Section 4